Monitoring Strategies for Evaluating Non-target Effects: Predicting Secondary Effects *a priori.*

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Example Publications of Interest

- Some of my friends

Effectiveness of Biological Control in Managing Invasive Species

- Biological control has shown significant potential in solving many invasive pest problems in a highly sustainable and environmentally friendly fashion.
  - Complete, Substantial and Partial control of many pests.
  - Clear economic value
    - $2 billion/ yr benefit and
    - Cost:benefit ratio of approximately 1:100+ cited.
  - Ecologically compatible in many, if not most situations.
    - May be only realistic tool in some natural areas.
- Biological control is not without its issues, however, as is the case with all methods of pest control or in taking no action at all.
  - There is now clear evidence that non-target and unwanted side effects can and do occur in association with some biological control projects.

Some Criticisms of Biological Control

- Poor or improper target selection.
- May not adequately impact the target species.
- Has potential to impact beneficial species including crops.
- Releases can and have caused damage to native non-target species.
  - May include direct attack, displacement of species, and/or indirect effects transferred through complex ecosystem interactions.
  - Impact on non-target species are typically unknown.
- Can spread unbounded throughout the environment.
- Inadvertent introductions of pests or hyperparasites/pathogens may occur with new releases.
- Process conducted haphazardly or at least not up to the standards of some concerned individuals.
- Microbes expected to have similar issues as other agents.
- Augmentation of native natural enemies even suggested a problem.
- The list of criticisms goes on, but my time is limited today.

How Likely? How Severe? What is the Risk? Can we predict it?

- Primary and Secondary Effects
  - Direct impact on targets & non-targets
- In-direct Effects
  - Competition and/ or compensation
  - Shared natural enemies
  - Vectors/ alternate hosts
  - Disruption of food-webs
    - Biotic or physical disruptions
- Realized Host Range may be dynamic (ecological host range)
  - Hosts and agent abundance and quality can affect performance
  - Competition within and between species
  - Refugia allow escape for some individuals or species
- Host Range Expansion
  - Adaptation to new hosts
  - Host shift likelihood, in Evolutionary time vs. Ecological time

This is becoming a long and onerous list!

Risk Identification

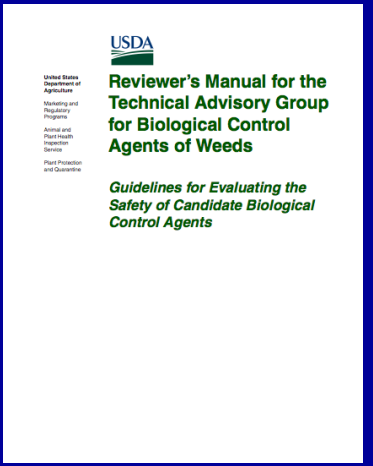
Risk = Severity of Event x Probability of Occurrence

(Cost/ event) (Events/ time)

- **Potential plant, animal or human pest/pathogen**
  - **Health threat**
  - **Economic damage**
  - **Nuisance**
- **Environmental Impacts**
  - **Habitat alteration**
  - **Non-target effects**
    - **Competitive exclusion**
    - **Alteration by interbreeding**
    - **Reduction of alternate hosts**
    - **Localized or complete extinction of non-target species**

Both Benefits and Risk must both be assessed to do the job correctly.

Scientific Approaches to Address Concerns:

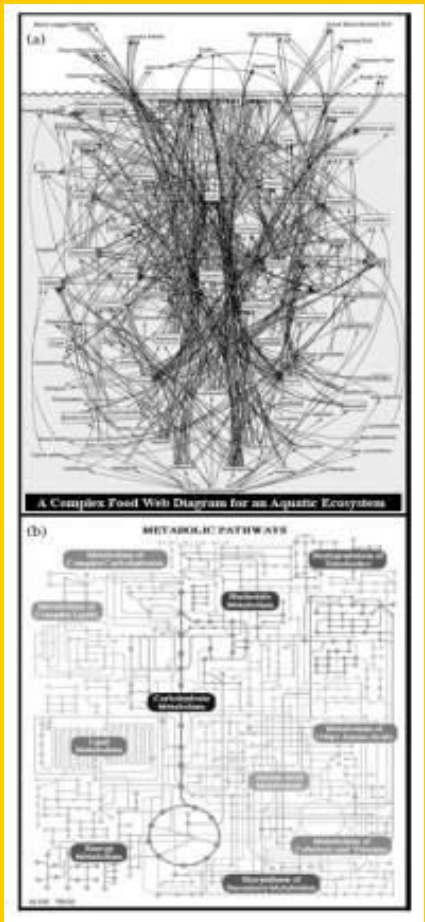


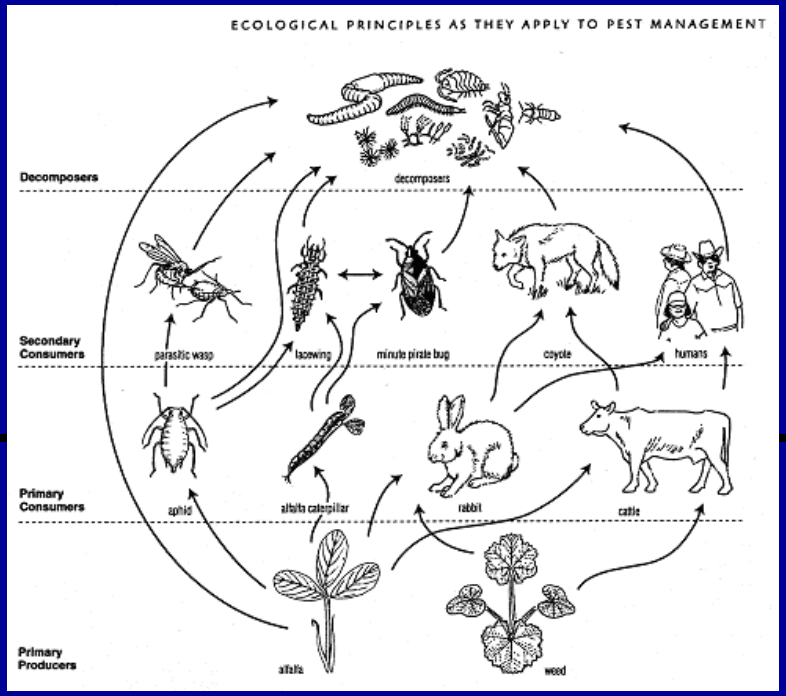
- Target Assessment [taken from APHIS weed biological control TAG Manual].
  - Assessment of threat caused by the target pest.
    - Impact, geographic distribution, potential for spread.
  - Taxonomic assessment and related non-target species.
    - Economically important or threatened/ endangered relative?
    - Biology, ecology and associations in country of origin?
  - Economic/ societal uses of target or closely related species?
  - Alternative control measures?
- Identification and Characterization of Natural Enemies
  - Systematics and host associations in the country of origin.
  - Host Specificity Assessments.
  - Efficacy evaluation on targets and non-targets.

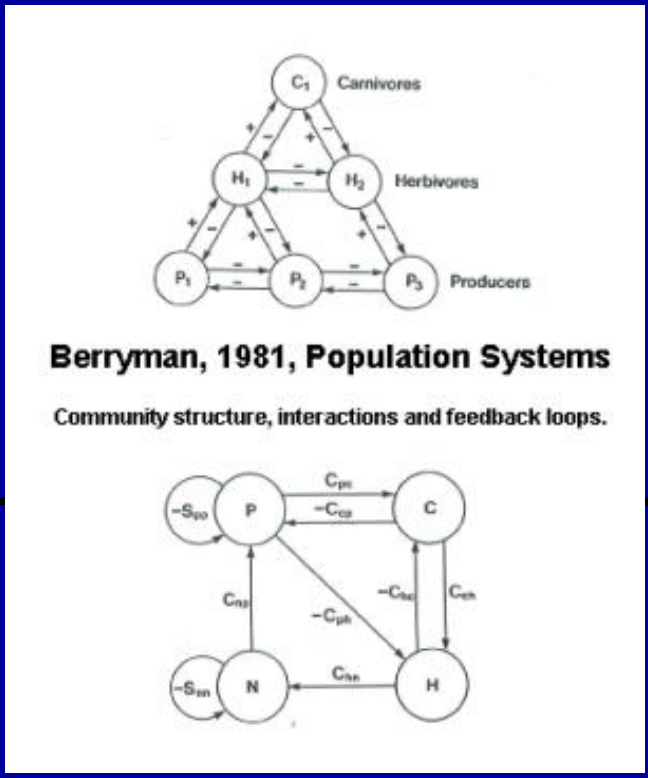
- Host Specificity/ Host Range Assessments
  - Host specificity testing
    - Test plant (arthropod) lists
    - Choice and no-choice tests
    - All life stages tested
  - Ecological host range in native areas
  - Projection of actual host range in introduction site
  - Adaptation/ evolution of expanded host range

- Efficacy of Natural Enemies
- Environmental Impacts
  - Human impacts
  - Economic impacts
  - Plant impacts
  - Mitigation methods
  - Edaphic effects
  - Food–web implications

Food Webs

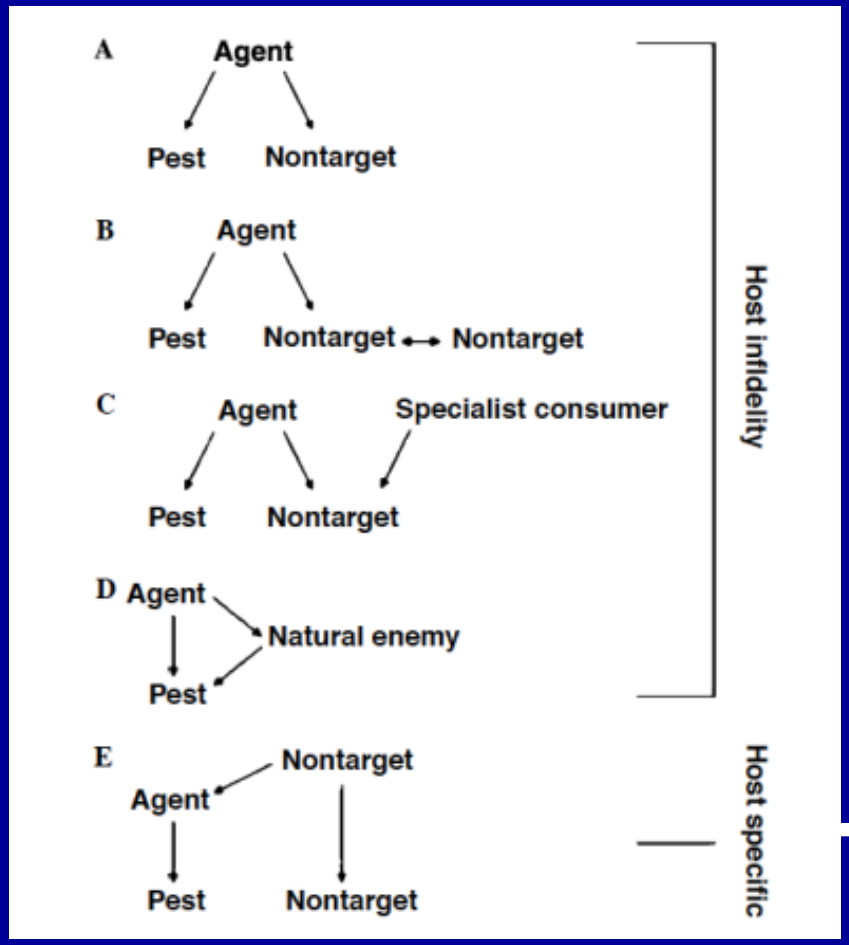

(a)
A Complex Food Web Diagram for an Aquatic Ecosystem
(b)
METABOLIC PATHWAYS


ECOLOGICAL PRINCIPLES AS THEY APPLY TO PEST MANAGEMENT
Decomposers
Secondary Consumers
Primary Consumers
Primary Producers
decomposers
parasitic wasp
lacewing
minute pirate bug
coyote
humans
aphid
alfalfa caterpillar
rabbit
cattle
alfalfa
weed


C1
Carnivores
H1
H2
Herbivores
P1
P2
P3
Producers
Berryman, 1981, Population Systems
Community structure, interactions and feedback loops.
P
C
N
H

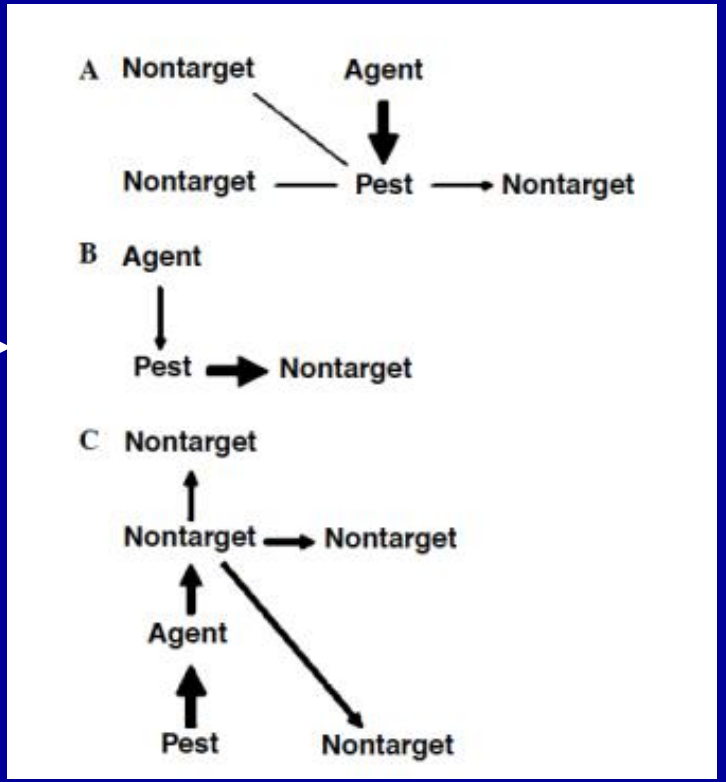
Community Food-Web Modules,

after Holt and Hochberg 2001; and Pearson and Callaway 2008.



Direct and Indirect linkages of Natural Enemies and Non-targets

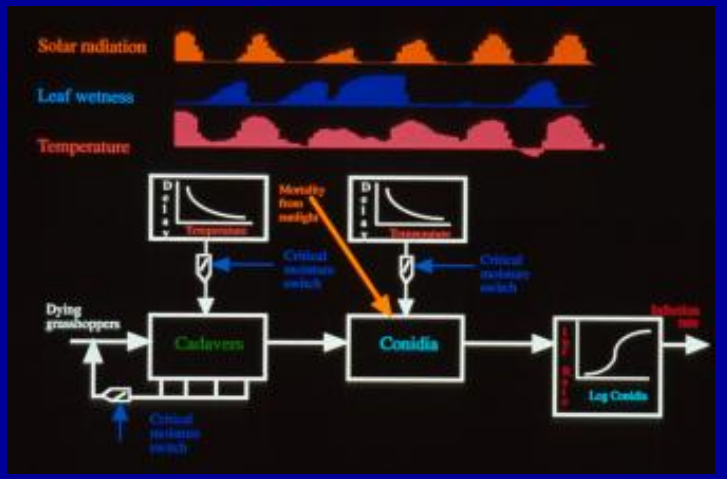
Host Specific Agents



A- Ecological Replacement
B- Compensatory Response
C- Food-web Interaction

Predictive Modeling

- Synthesis of complex biological data.
- Synchrony of host and natural enemies in different habitats and climatic conditions.

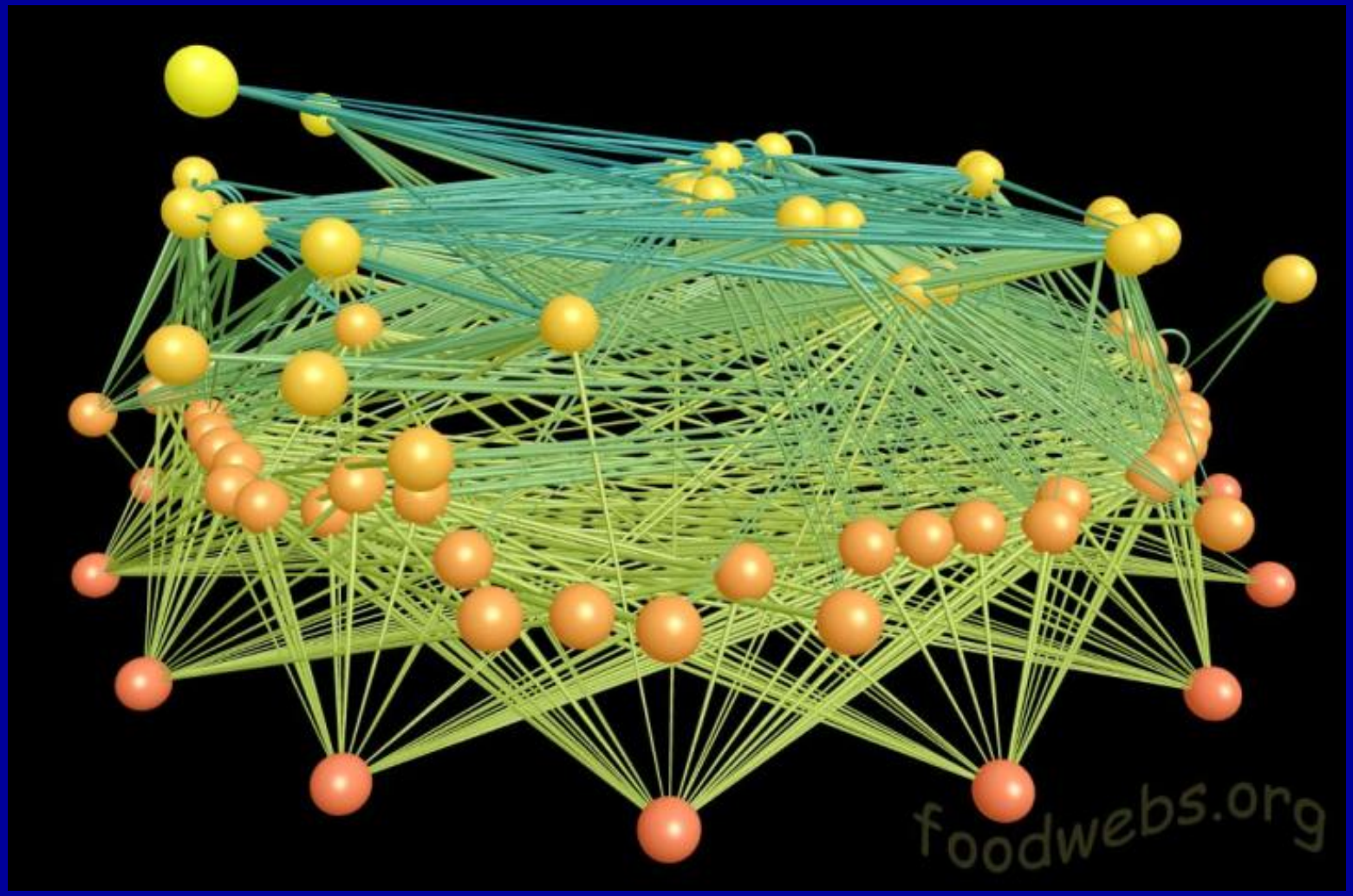


- Direct and indirect impacts on population growth and survival.
- Spatial dynamics & natural enemy spread.
- Prediction of impact caused by natural enemy activity.
- Potential of synergies to more fully impact target pests.
- Better *post-hoc* assessment than *a priori* prediction.

Mutualistic Webs of Species

John N. Thompson, Science Vol. 312, 2006

(www.foodwebs.org)



"Specialization within mutualistic food webs tends to be nested. …"

"… interactions between predators and prey or herbivores and plants are often more compartmentalized, forming smaller clusters within the broader interacting web (see citation). "

Lewinsohn, T., V. Novotny, Y. Basset, *Annu. Rev. Ecol. Syst. 36, 597 (2005).*Krause, A., K. Frank, D. Mason, R. Ulanowicz,W. Taylor, *Nature 426, 282 (2003).*

Prediction *a priori* is currently improbable in most complicated systems no matter how good our models.

- Biological details matter!!!
- Many direct effects are predictable with current biological knowledge and testing data.
- Even assessing indirect effects is practical in simple agro-ecosystems, although harder in more complex natural systems.
- More distant food-web implications are difficult to visualize, quantify and predict.
- Is this a deal killer for biological control with regulatory agencies? I don't think so.
- Hopefully, we can assess as we go forward.

Pre- and Post-Program Evaluations and Monitoring

- Needs Assessment (prerelease)
- Benefit/ Risk Assessment (prerelease)
- Impact Assessment via Monitoring
- Wider Ecological Assessment
- Economic Assessments
  - By economists in cooperation with biologists
- Overall benefit to society should be evaluated (pre- and post-release)

Effective Ecological Monitoring

Lindenmayer and Likens, 2010

Reasons to Conduct Biological Monitoring

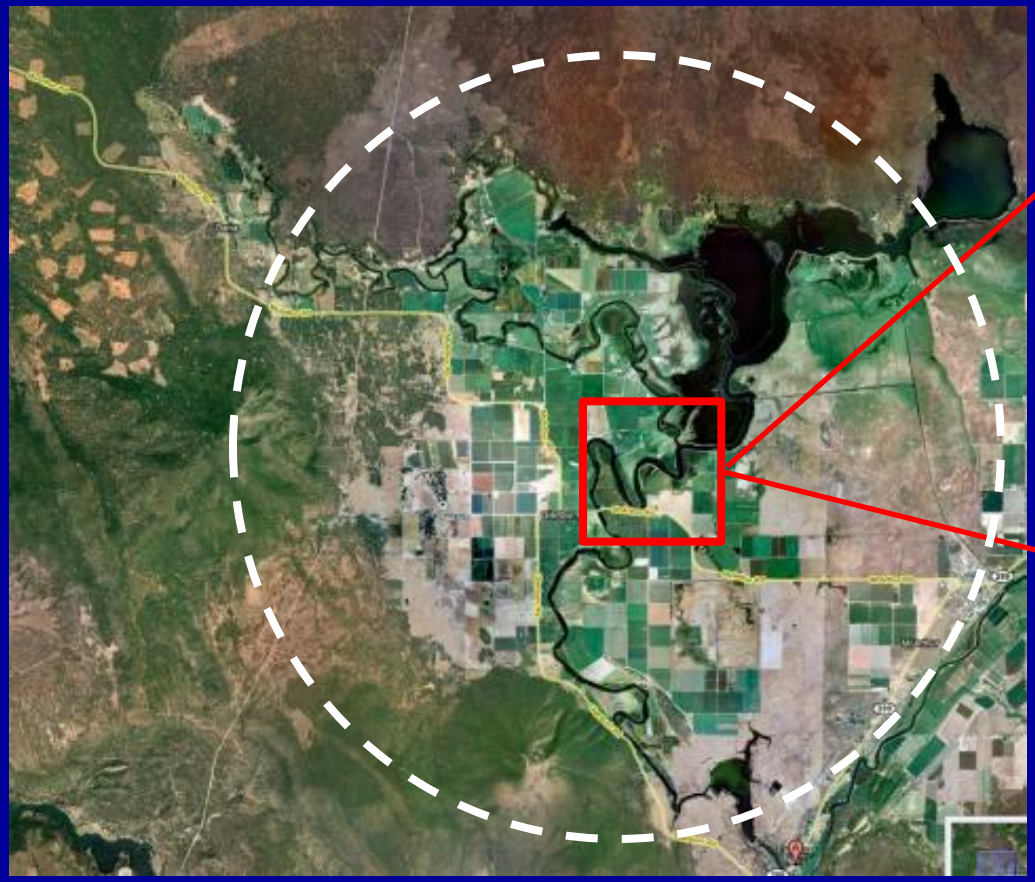
- Documenting status and providing baseline for comparison.
- Evaluating ecological responses to natural disturbance, ecological experiments or introductions/ augmentations.
- Detecting/ evaluating change in ecosystem structure or function.
- Generating new questions about populations, communities, etc.
- Providing empirical data for ecological theory and models.
- Data mining when exploring new questions.
- All these reasons relate directly to why we need to monitor biological control programs.

Environmental Monitoring Programs

Lindenmayer and Likens, 2010

Should:

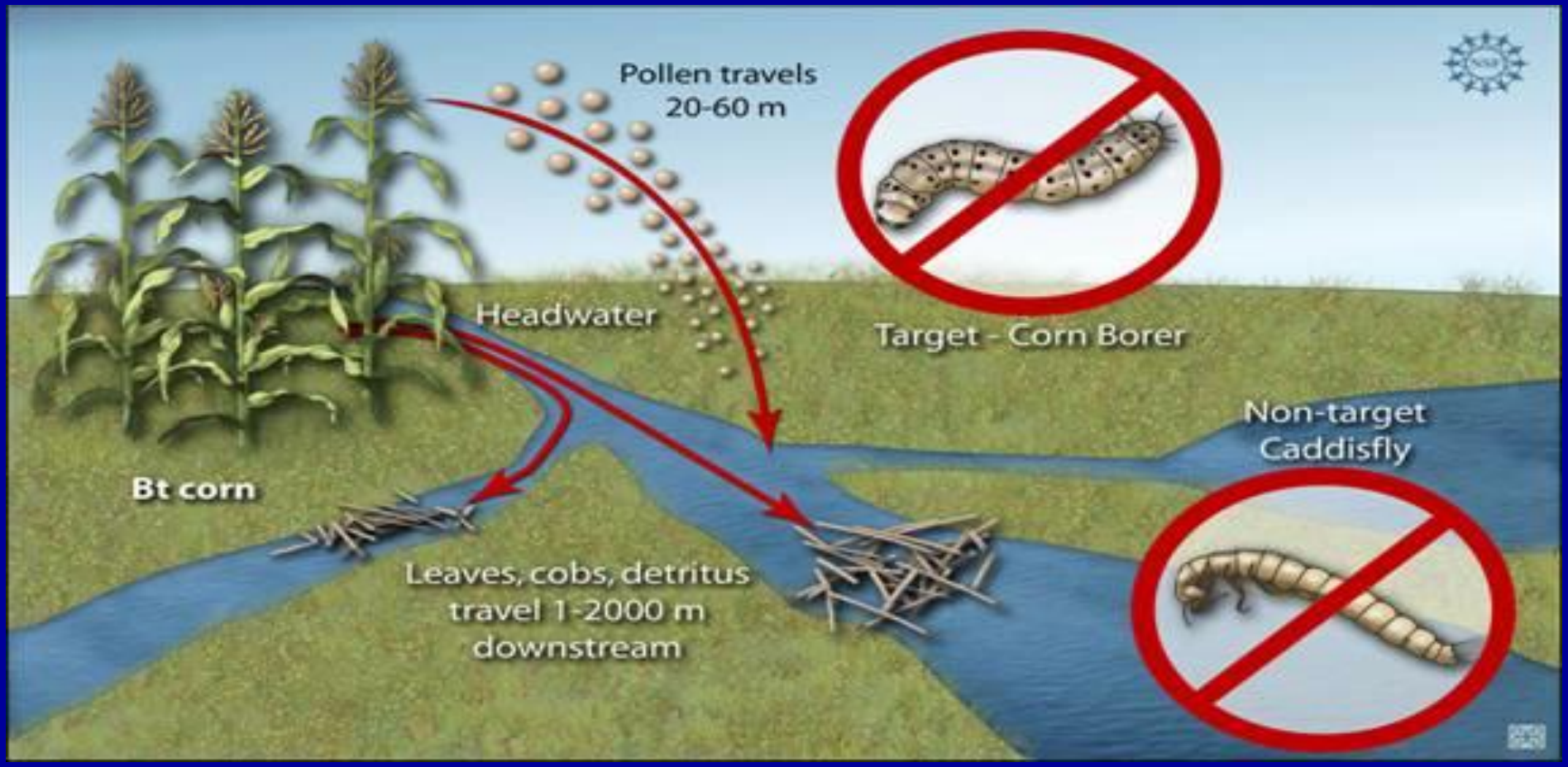
- **not just be conducted just to meet regulatory requirements.**
- **have specific goals and scientific-based hypotheses.**
- **be linked with embedded experiments addressing key issues.**
- **be properly designed, based on a structural and functional understanding of the targeted ecosystem.**
- **avoid collecting a laundry list of data without purpose.**
- **actively assess, evaluate and share data with the scientific and regulatory community within a reasonable timeframe.**
- **maintain data integrity, assess and up-date assumptions and approaches while not severely altering methodology.**



Spatial Universe of Concern

- Obvious area of influence.
- Dynamics may be affected by movement of other organisms or physical substances.
- Must also consider meta-population dynamics.
- Here we were sampling microbial communities.

May need to think outside of the box or field, as the case may be.



Common Things to Measure when Monitoring Pathogens

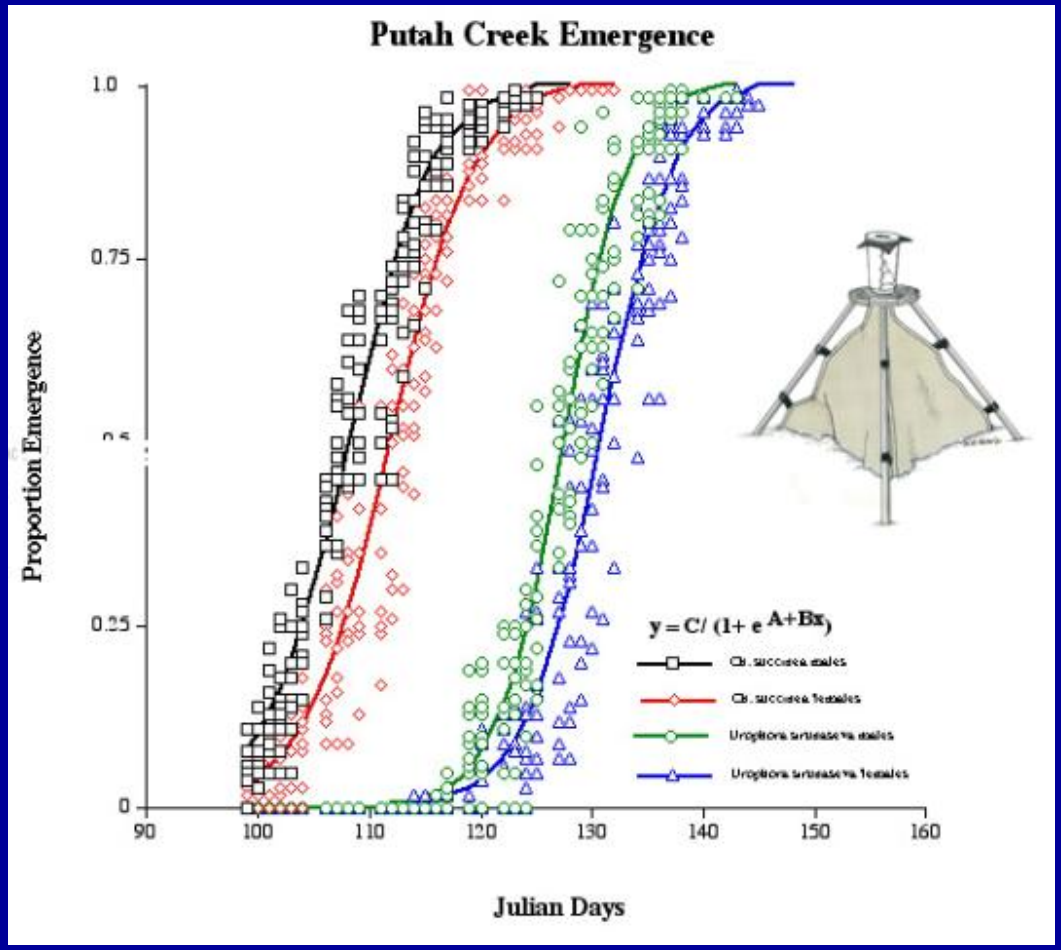
- Age specific population densities of host and pathogen.
  - Inoculum levels, dormant stages, other hard to see or assess stages.
- Signs of disease (lesions), prevalence levels, plant defoliation.
- Mortality rates, fecundity rates, inoculum persistence/ viability, virulence and other time-dependent processes.
- Changes in behavioral responses of targets and non-targets.
- Changes in phenology linked with critical environmental conditions that may affect synchrony with other organisms.
- Types of organisms to consider when monitoring.
  - Closely related organisms (centrifugal/ phylogenetic assessments).
  - Critical habitat associates.
  - Keystone ecological species.
  - Species of economic concern.

Meteorological/ Abiotic Environmental Sampling and Assessment

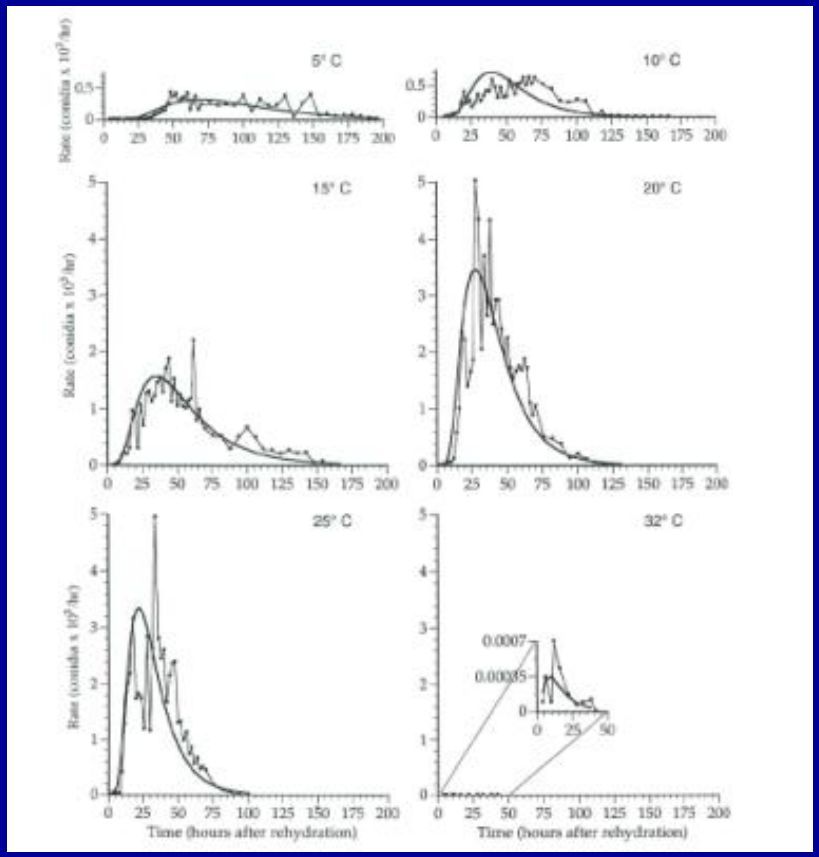
- Surface Water Temperature
- Subsurface Water Temperature
- Total Nitrogen (TN)
- Nitrate Nitrogen (NO_3-N)
- Ammonium Nitrogen (NH_4-N)
- Soluble Reactive Phosphorus
- Total Phosphorus

Environmental Monitoring Tools

- Sampling methods
  - wide range of approaches
  - must consider accuracy/ precision (statistical design)
  - BACA designs (before and after comparative assessment)
- Assessing biological states
  - population levels
  - environmental conditions
- Assessing biological rates
  - within and between species
- **Important to shed light on mechanisms of interaction.**

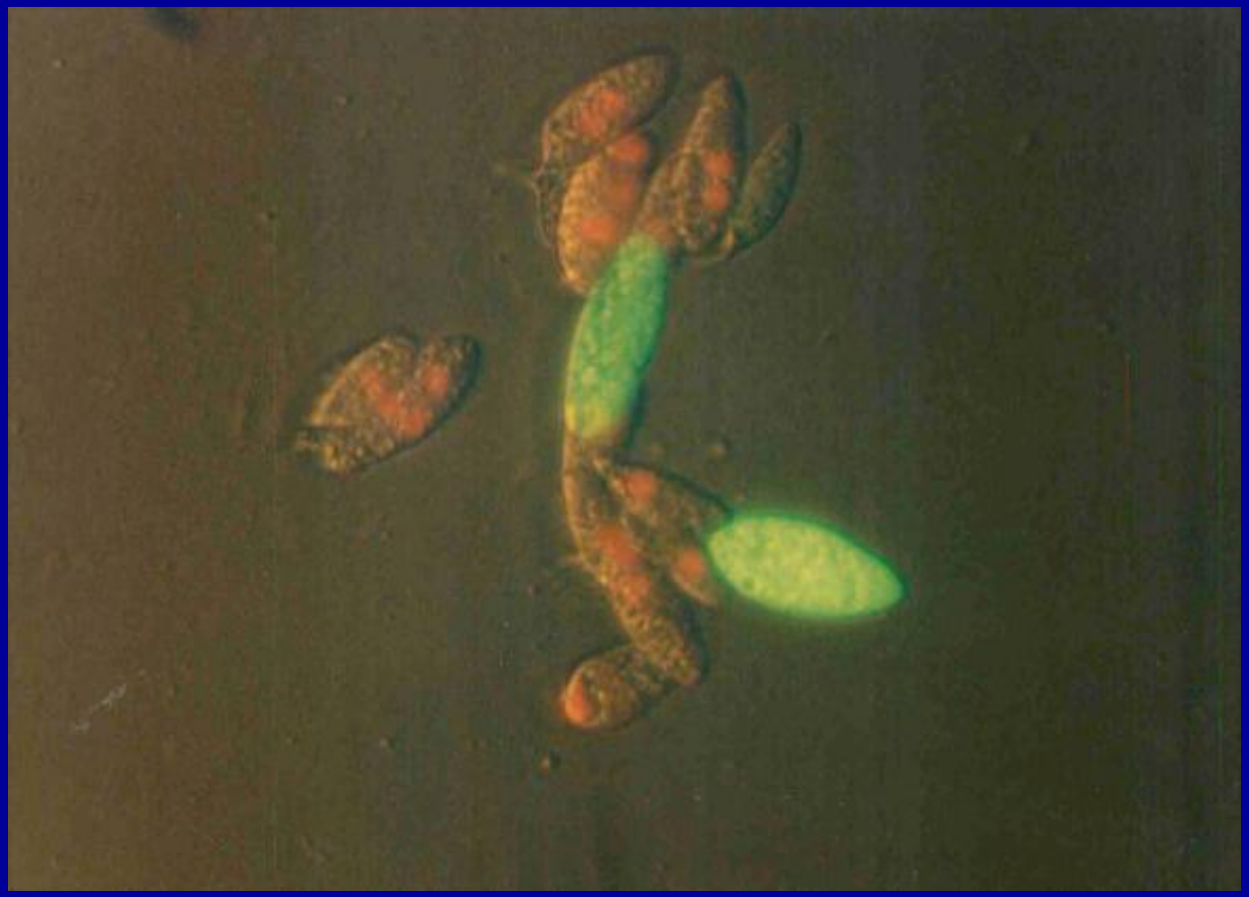


Linking Models with Monitoring



Prediction of biological processes under variable environmental conditions using quantitative models can help document understanding.

Inoculum Viability Assessment: Vital stains of *Z. radicans* conidia



Biochemical, molecular or other sophisticated tools may aid assessments, improve accuracy, speed response time and reduce costs.

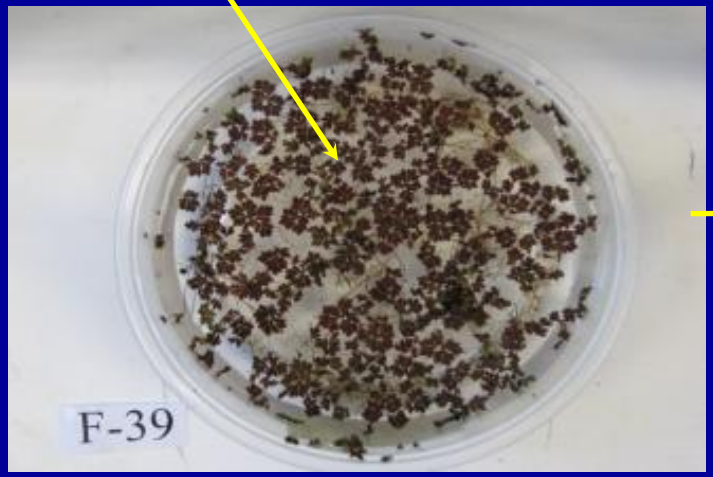
Plant, Insect and Disease Assessment

Monitoring requires a real commitment
and REAL RESOURCES.
You may also even have to get muddy!!!

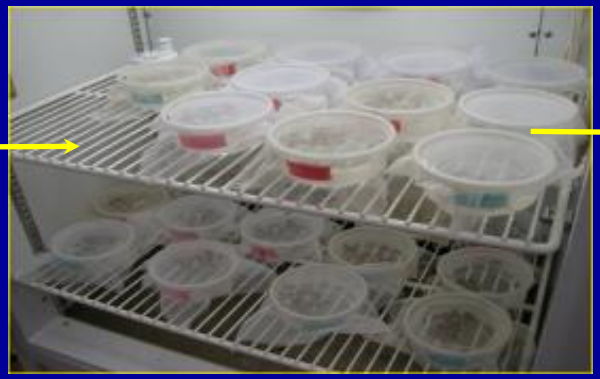
Field collections

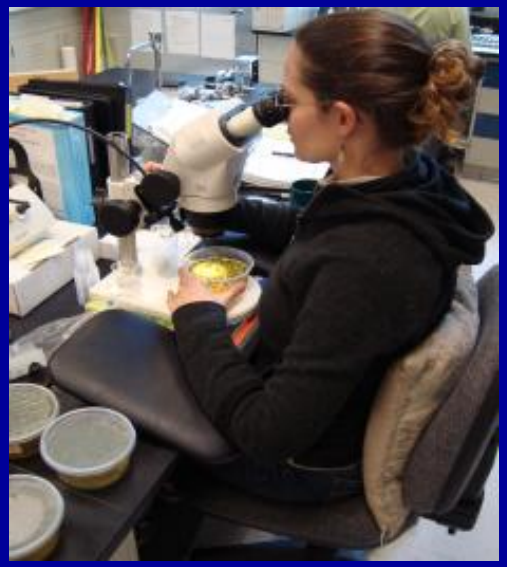
Disease Prevalence Sampling and Assessment

May require combination of field and lab efforts.



Incubated for 2 weeks at 25° C





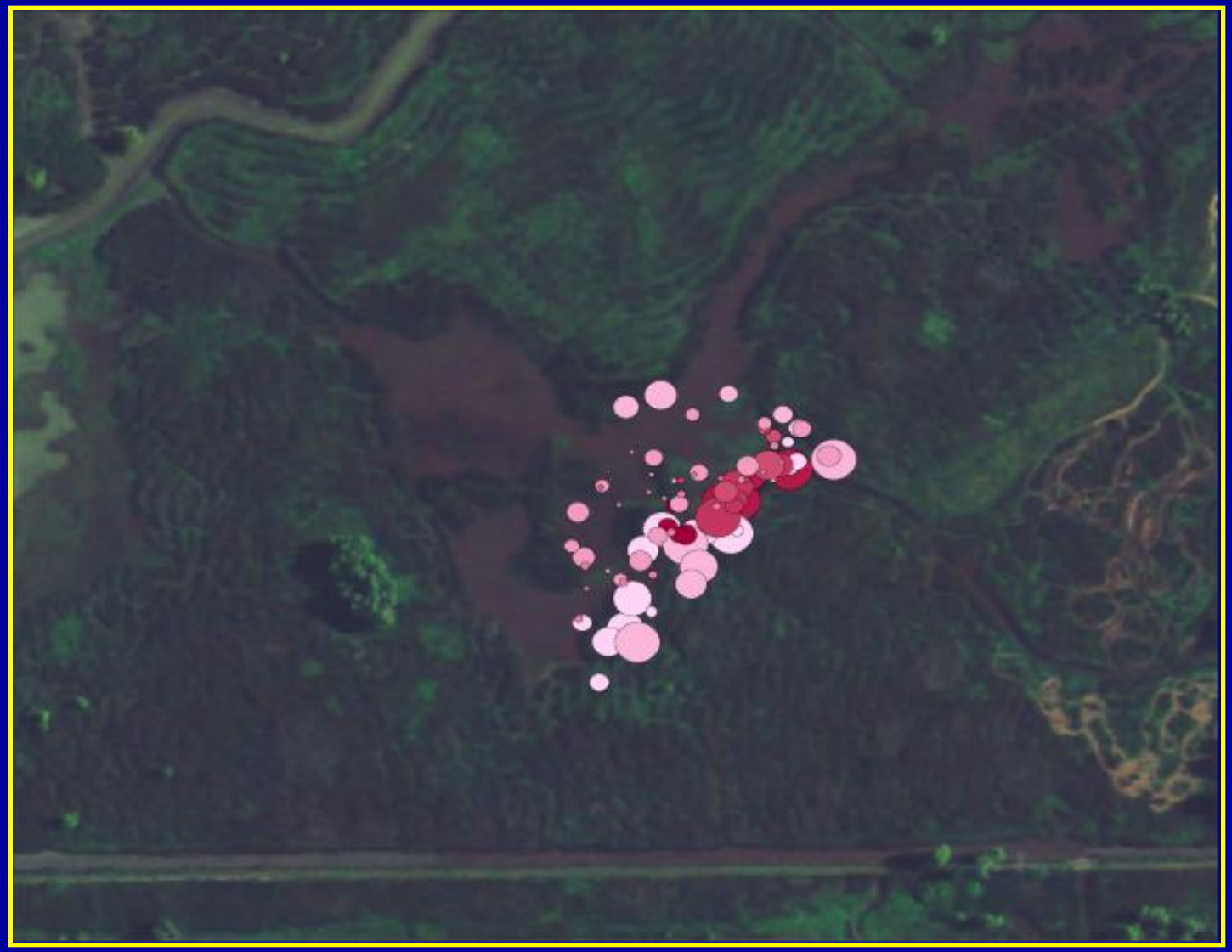
Samples transfer to rearing cups on Day 1-2

Age specific counts made 4-5 times

Results summed up over assessment days and age structure at time of collection calculated based on degree-days.

Spatial Patterning of Response, Wild Goose Club

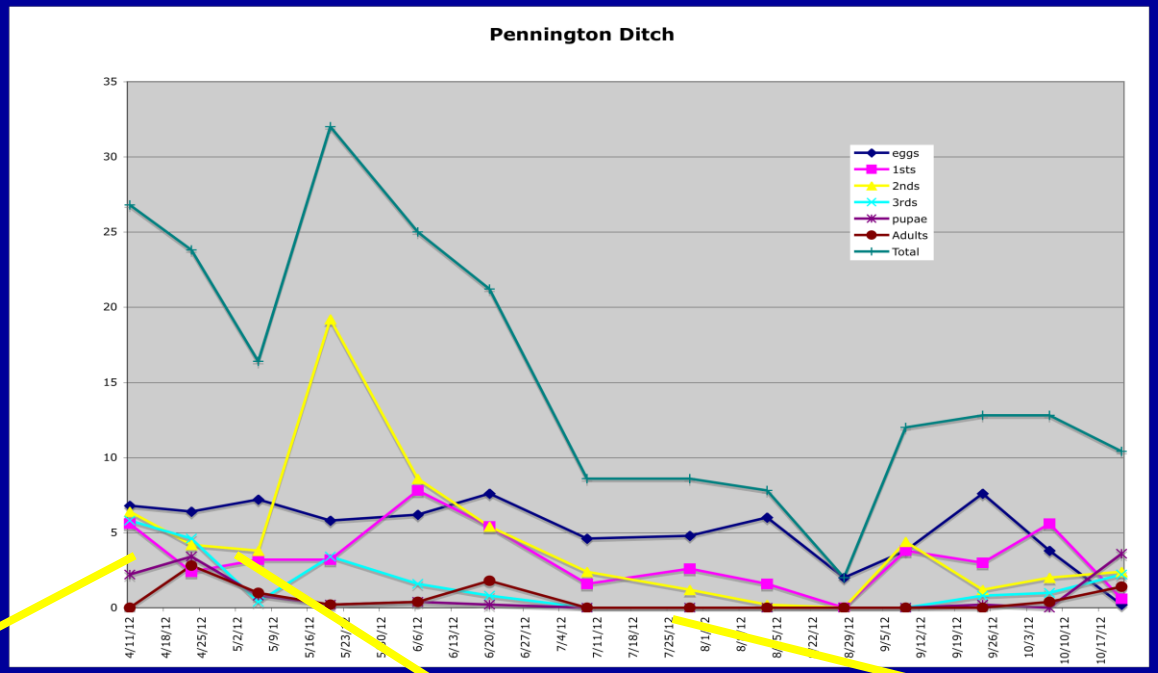
Changes in prevalence throughout the sampling season

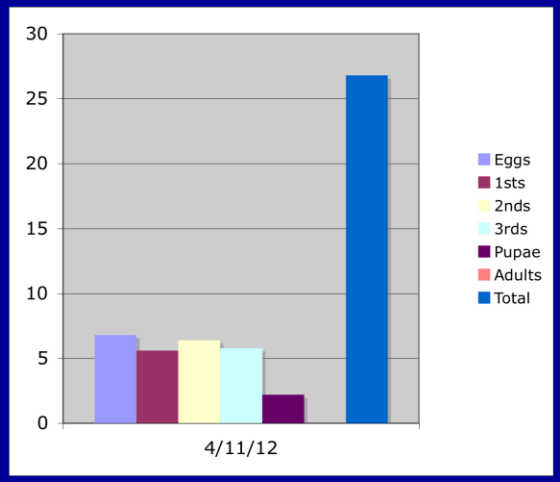


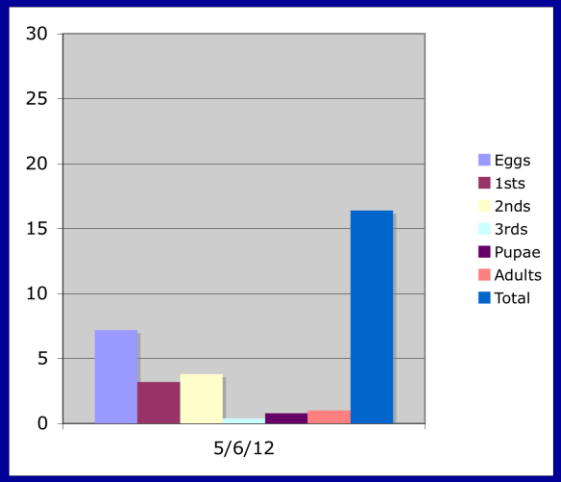
Data projection back into the real world improves understanding.

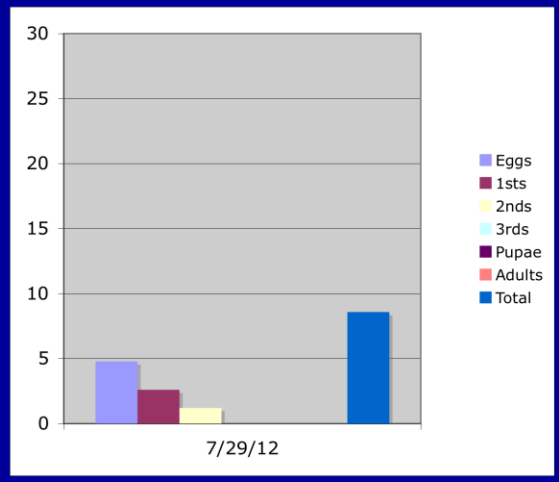
Greylodge Wildlife Refuge
Population Age Structure

May require viewing the same or independent validation data in different ways to see and verify impact.



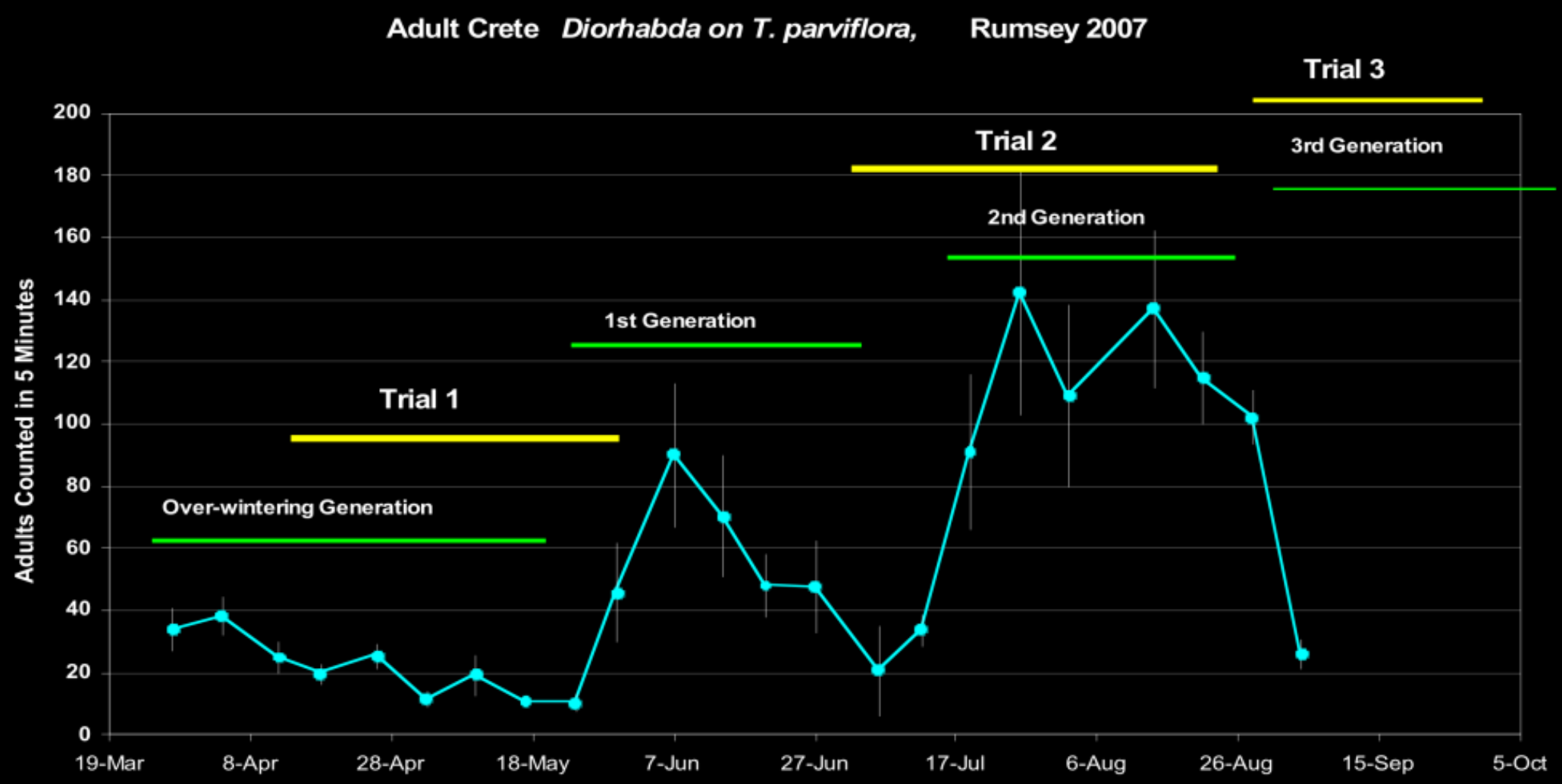






Embedding Experiments with Monitoring: an example from Saltcedar

- Monitoring for non-target impacts of concern.
- Conducted to assess the direct and indirect effects of biological control on saltcedar and associated flora and fauna.
- Detailed assessments at several release sites for multiple years through revegetation/ recovery.
- Conducted using a variety of techniques and experienced personnel from many Agencies.


Adult Crete Diorhabda on T. parviflora, Rumsey 2007
Trial 3
Trial 2
3rd Generation
2nd Generation
1st Generation
Trial 1
Over-wintering Generation
Adults Counted in 5 Minutes
200
180
160
140
120
100
80
60
40
20
0
19-Mar
8-Apr
28-Apr
18-May
7-Jun
27-Jun
17-Jul
6-Aug
26-Aug
15-Sep
5-Oct

3 species of *Tamarix* and 2 of *Frankenia* tested in California field release study

Early Season

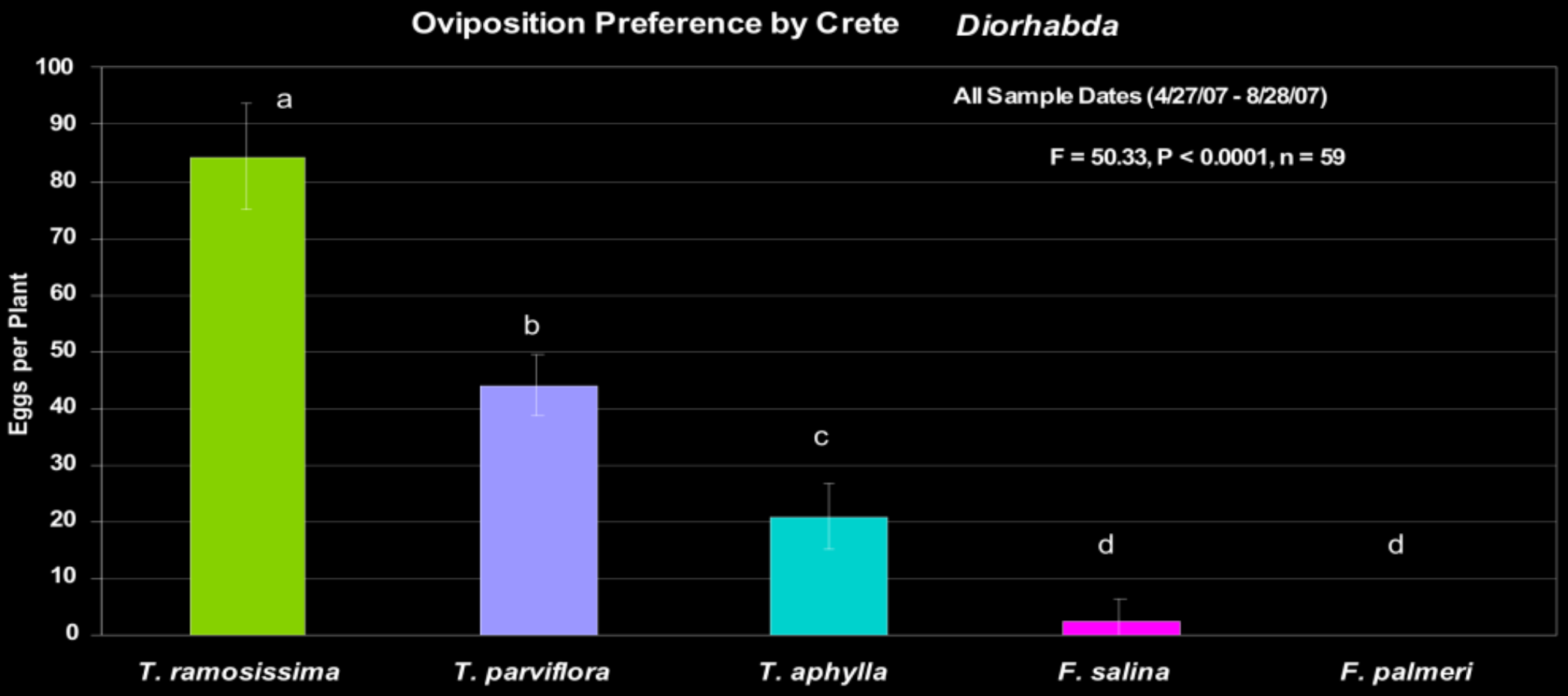
-low beetle #s
-good vegetation

Mid Season

-moderate to high beetle #s
-fair vegetation

Late Season

-very high beetle #s
-poor vegetation


Oviposition Preference by Crete
Diorhabda
All Sample Dates (4/27/07 - 8/28/07)
F = 50.33, P < 0.0001, n = 59
Eggs per Plant
100
90
80
70
60
50
40
30
20
10
0
a
b
c
d
d
T. ramosissima
T. parviflora
T. aphylla
F. salina
F. palmeri






Some egg laying still occurs on *Frankenia salina* however reviewer felt that the impact would be negligible, especially since most *Frankenia salina* grows in tidally influenced areas or alkali seeps where *Diorhabda* pupae are not expected to easily survive. USDA continues to monitor and test host shifting in the lab.

In Summary

- Exotic and invasive pests appear to be an ever increasing problem now and on into the future.
  - Both in agriculture and the natural environment.
- Many different techniques are going to be needed to solve these problems.
- All methods of pest control present benefits and some risk including biological control.
- Biological controls have worked effectively with a minimum of negative side effects, however, careful evaluations are and will continue to be needed.

- **Prediction of non-target impacts is reasonable with direct effects but difficult at best for in-direct effects and maybe impossible in some cases.**
- **Biological control programs should continue with careful regulatory oversight and parallel environmental monitoring.**
- **Environmental monitoring should be conducted with focused efforts targeting specific objectives, be reasonable in scope and open in nature.**
- **Adequate resources need to be designed into programs to allow monitoring for a reasonable number of years.**
- **Teams of biologists and ecologists need to work together on these issues rather then in conflict.**
- **Benefits must be included along with Risks in the Regulatory Process!!!**